A DIGITAL RADIOSONDE SYSTEM

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by

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ABSTRACT

A study of the present methods and equipments used in obtaining upper air meteorological data indicated a need for a new system capable of interfacing with digital equipment. This work deals with establishing the parameters, methods of implementation, circuit design, construction, and testing of such a system. Sampling, pulse width modulation, time multiplexing, pulse width to digital conversion, and interfacing with the digital computer are discussed. The proposed integrated circuit radiosonde system was constructed and tested with results indicating an improvement over the existing methods.

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1. Introduction.

At present, about one thousand radiosondes are launched each day to obtain data for weather forecasting. There are two types of radiosondes presently in use to provide this information; the AN/AMT-4 (1680 MHz) and the AN/AMT-11 (403 MHz). Naval units primarily use the AN/AMT-11, while shore stations use the AN/AMT-4. The operation of both units is identical except for the transmitting frequency. Therefore, only the AN/AMT-11 will be discussed.

The AN/AMT-11 is a balloon-borne, expendable, instrumentation package consisting of sensing devices and a radio transmitter for determining and transmitting temperature, pressure, and humidity to a ground based recording station. The desired range and accuracy of data is as follows:

ALTITUDE -	0 to 100,000 feet
TEMPERATURE -	50 °C to -90 °C; $\pm$ 1 °C
PRESSURE -	1060 mb to 5 mb; $\pm$ 2 mb
HUMIDITY -	15% to 90% $\pm$ 1%

The temperature and the humidity transducers are of the resistive type, while the pressure transducer, called a BAROSWITCH, is an aneroid barometer mechanically coupled to a switching plate. The switching plate connects the temperature element, humidity element, or a reference resistor into the grid circuit of a blocking oscillator. The 403 MHz carrier is modulated at an audio frequency by the blocking oscillator; the frequency being dependent upon which element the baroswitch has connected to the grid circuit. There are no solid-state devices employed in the air-borne unit.

The ground station receiver-decoder converts the audio frequency to voltage and produces a chart recording which must then be read,

interpolated, and corrected to yield the desired data. This data is then manually encoded and transmitted over established communication links to a central weather facility where the data from all stations is plotted on large area charts. Weather predictions are then made from these charts. Sensor inaccuracy and human errors in reading and encoding data are large contributors to the over all error.

After extensive testing of the radiosonde system, CORBEILLE [12], concluded, "No one sensing element can be singled out as being worse than the others and, conversely, none better. If accurate data are to be obtained by radiosonde flights the entire system must be considered inadequate and improvements must be initiated. --- The baroswitch reaches its limit of usefulness as a pressure sensing device in the troposphere and can be considered a major contributing factor to the inadquacies of the radiosonde system. --- Continuous transmission of relative humidity should be provided. Ozone is an important atmospheric constituent which is not measured on an operational basis. However, it is concentrated mainly above 15km where humidity becomes of little importance, and the design of future radiosondes would do well to include replacement of the humidity signal above 15km by telemetry of an ozone signal."

2. Design Considerations.

The main problem in instantaneous or "real time" weather prediction is data recovery and transmission to the weather facility. The radiosonde system causes a large part of this time delay. For this reason, a primary consideration of a new system is that it should provide digital information which can be recorded at the ground station during balloon ascent. This raw data can then be transmitted on a high speed digital network on command from a Weather Central and entered directly into the computer. The same data link could be used for retransmission of completed forecasts. Fig. (1) depicts this system in block diagram form. The environment of the airborne package is a serious problem. The sensors and all circuitry must function properly in ambient temperatures from 50°C to -90°C and humidity from 0 to 95%. For a new system size and weight must be kept to a minimum, and data will be transmitted at least ten times a second with an accuracy which is an order of magnitude better than the present system. The present radiosonde costs about forty dollars. The transmitter will operate on a frequency of 403 MHz with a power output of about six watts.

Taylor [13] indicated a desire to measure other parameters during a sounding, such as ozone content. Therefore, the radiosonde should be capable of measuring more than three parameters, if desired by the launching facility.

2.1 Transducers.

The temperature sensor now in use may prove to be satisfactory. If not, many similar transducers are available. The humidity sensor now in use is not of the quality commensurate with the data required. A new humidity transducer should be developed. An accurate pressure

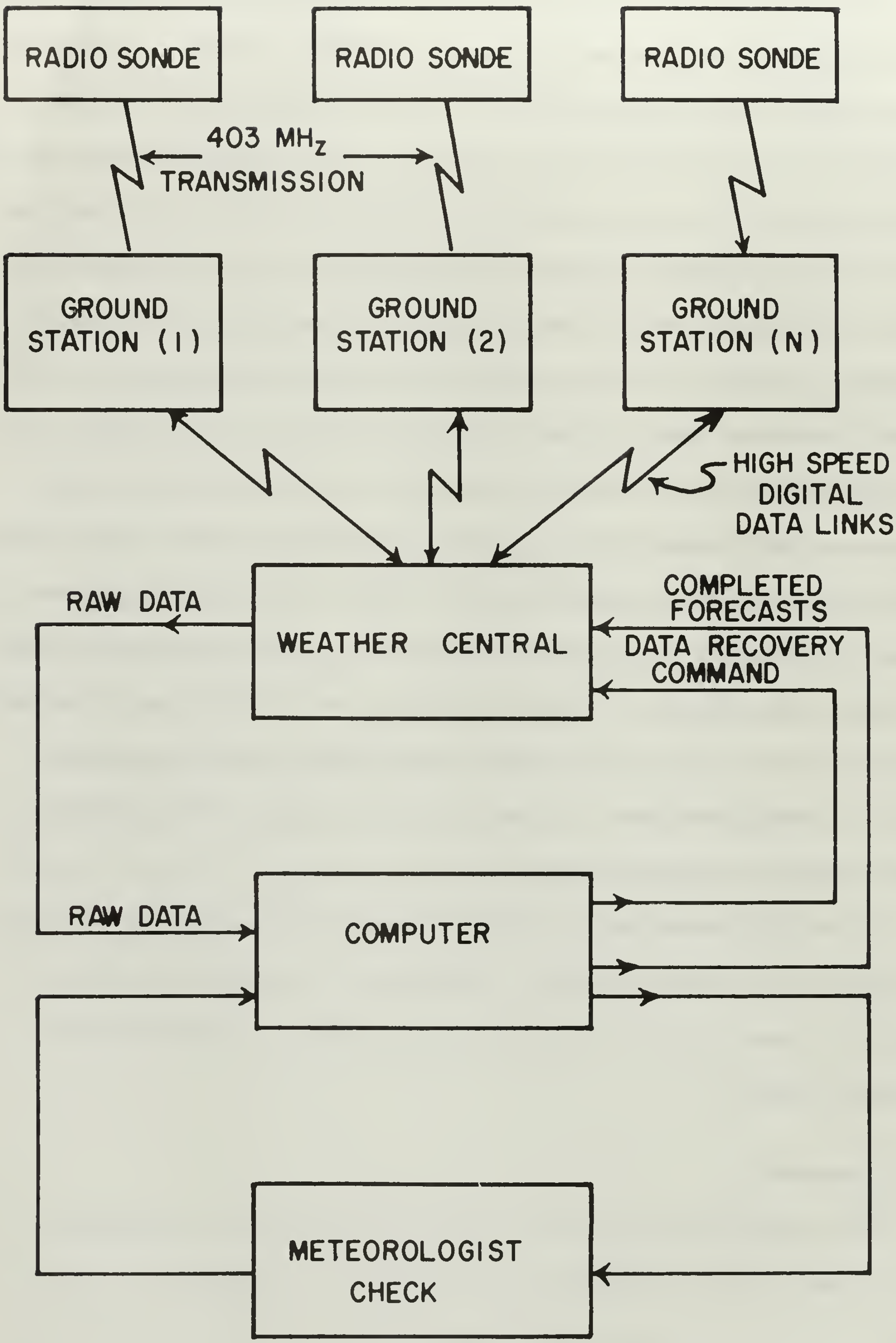

Fig 1 Digital Radiosonde System Communications and Information Links

sensor should be developed. This sensor could be of the resistance, voltage, or current type. Such pressure transducers are available, but completely out of the economic range of an expendable radiosonde system.

TABLE I

Summary of Design Considerations

INFORMATION FORMAT	- Digital
CHANNEL CAPACITY	- Six
TRANSDUCERS	- Resistance, voltage, or current
SIZE	- Minimum
WEIGHT	- Minimum
COST	- Less than $50.00
BATTERY DRAIN	- Minimum
FREQUENCY	- 403 MHz
POWER OUTPUT	- 6 watts
SAMPLE RATE	- 10 samples/sec
ACCURACY AND RANGE:	
TEMPERATURE	- 50°C to -90°C; $\pm$ 0.1°C
PRESSURE	- 1060mb to 5 mb; $\pm$ 1mb
HUMIDITY	- 10% to 90% $\pm$ 0.1%
INFORMATION READOUT	- Computer page printer, plotter, etc.

3. Implementation.

The entire system will be explained in block diagram form. A three channel system was designed for test purposes. Additional channels may be easily added.

3.1 Airborne Unit.

The major consideration in the airborne unit is the modulation scheme. Pulse duration modulation (PDM) of the 403 MHz carrier was chosen for the following reasons:

a. Simplicity

b. Relative noise immunity

c. Low power consumption

d. Easily capable of transmitting twelve binary bits of information at the desired rate

e. Availability of 2 MHz bandwidth in the 403 MHz range

The PDM scheme was implemented in the following manner. A clock, lms on and 10 ms off, initiates a ramp on each pulse, as sown in Fig. 2. The clock pulse also triggers a three state counter with possible states 000, 100, 010, and 001. When each successive state of the counter is in the "1" state a constant current source is switched to a resistive transducer. The voltage across the transducer and the ramp are compared and a pulse is generated when the ramp voltage is greater than the transducer voltage. This pulse then enables the transmitter.

For example, assign count 100 to temperature, 010 to pressure 001 to humidity, and 000 for synchronization.

The off time was used for synchronization in order to conserve battery power. On the trailing edge of the clock pulse, Fig. 3a, a ramp voltage is initiated, Fig. 3b. At the same time, the counters assume the

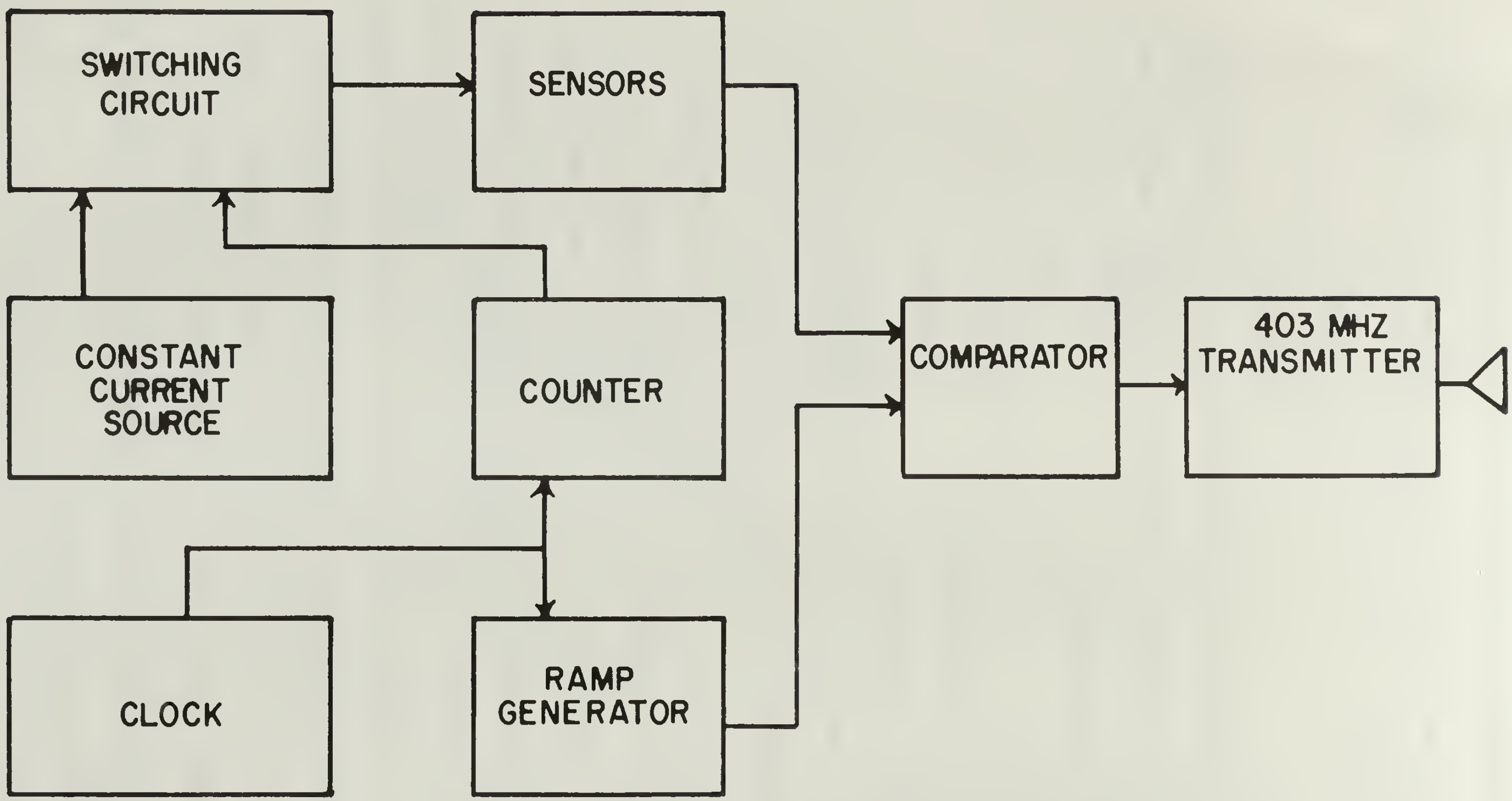

Fig. 2 Radiosonde Block Diagram

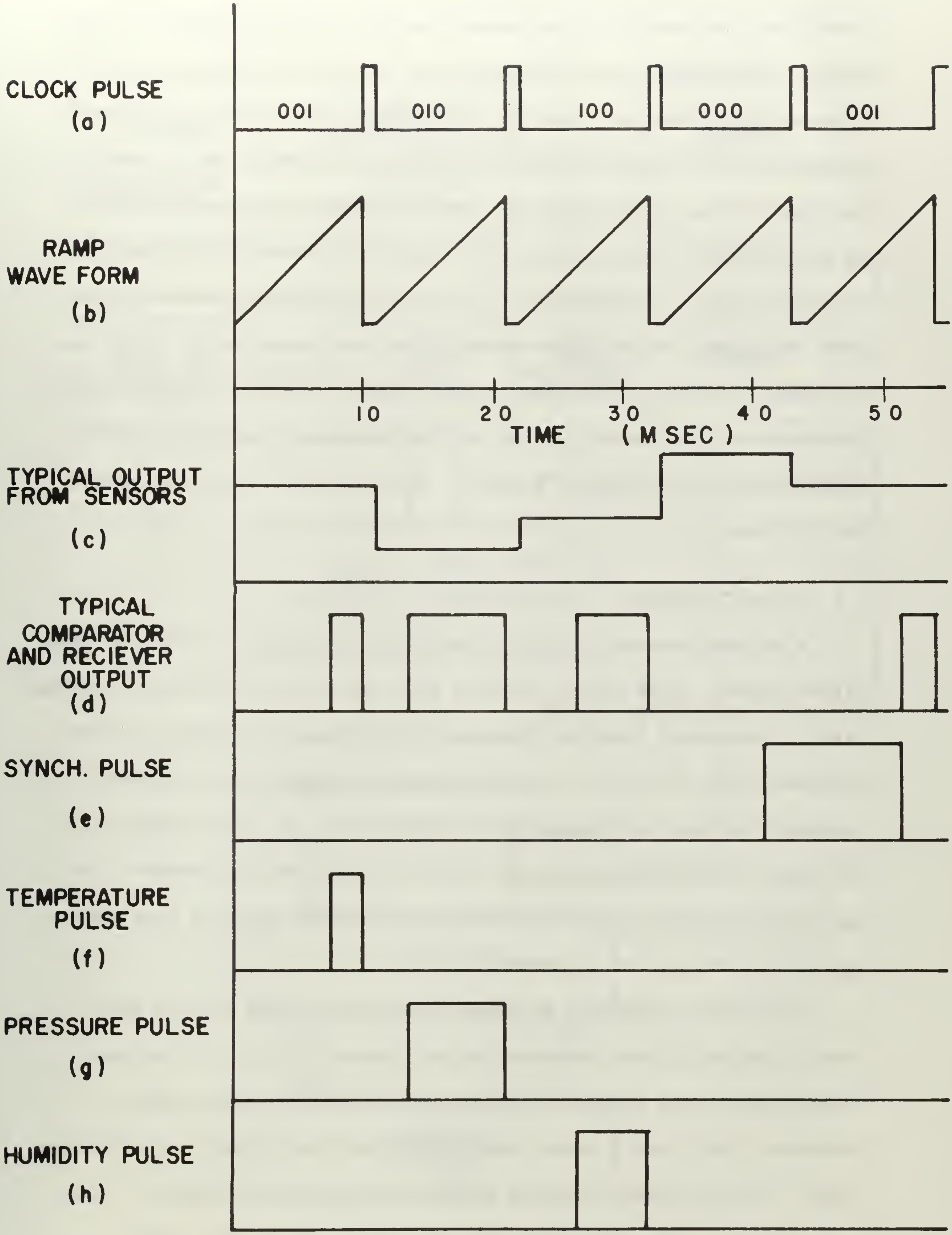

Fig 3 Radiosonde System Waveforms

state 100, thus switching the current source to the temperature transducer. This current, passing through the resistive transducer, produces a potential difference across it. In the comparator the ramp voltage is compared to the voltage across the temperature element, and a pulse is generated during the interval the ramp is greater, as seen in Fig. 3d. On the next clock pulse the counter assumes the state 010 and the pressure pulse width is generated. In a similar manner the humidity pulse width is formed. On the fourth clock pulse the counter state is 000 and no sensor is switched into the circuit. This, in effect, is an infinite resistance on the current source and the comparator receives a sensor voltage equal to the supply voltage. Thus no pulse is produced during the 000 count.

3.2 Ground Equipment.

A 403 MHz receiver, having a bandwidth of 2 MHz, receives the transmitted signal. This signal contains noise as well as the desired information. A threshold detector determines the presence or absence of the information as in Fig. 4. In performing this function the threshold detector recovers the transmitted waveform, Fig. 3d. This signal is the input to the synchronization lock-on circuit and the decoder. In the synchronization circuit the absence of a pulse during a time interval of more than 11 ms is sensed.

This circuit produces an output pulse of at least 1 ms in duration at the end of each synchronization interval, Fig. 3e. The synchronization pulse resets the decoder following each pulse train. Therefore, each time a pulse train is received the decoder is positively reset; also positively disabled if the pulse train is improper. From the decoder, there are three outputs; one for temperature, one for

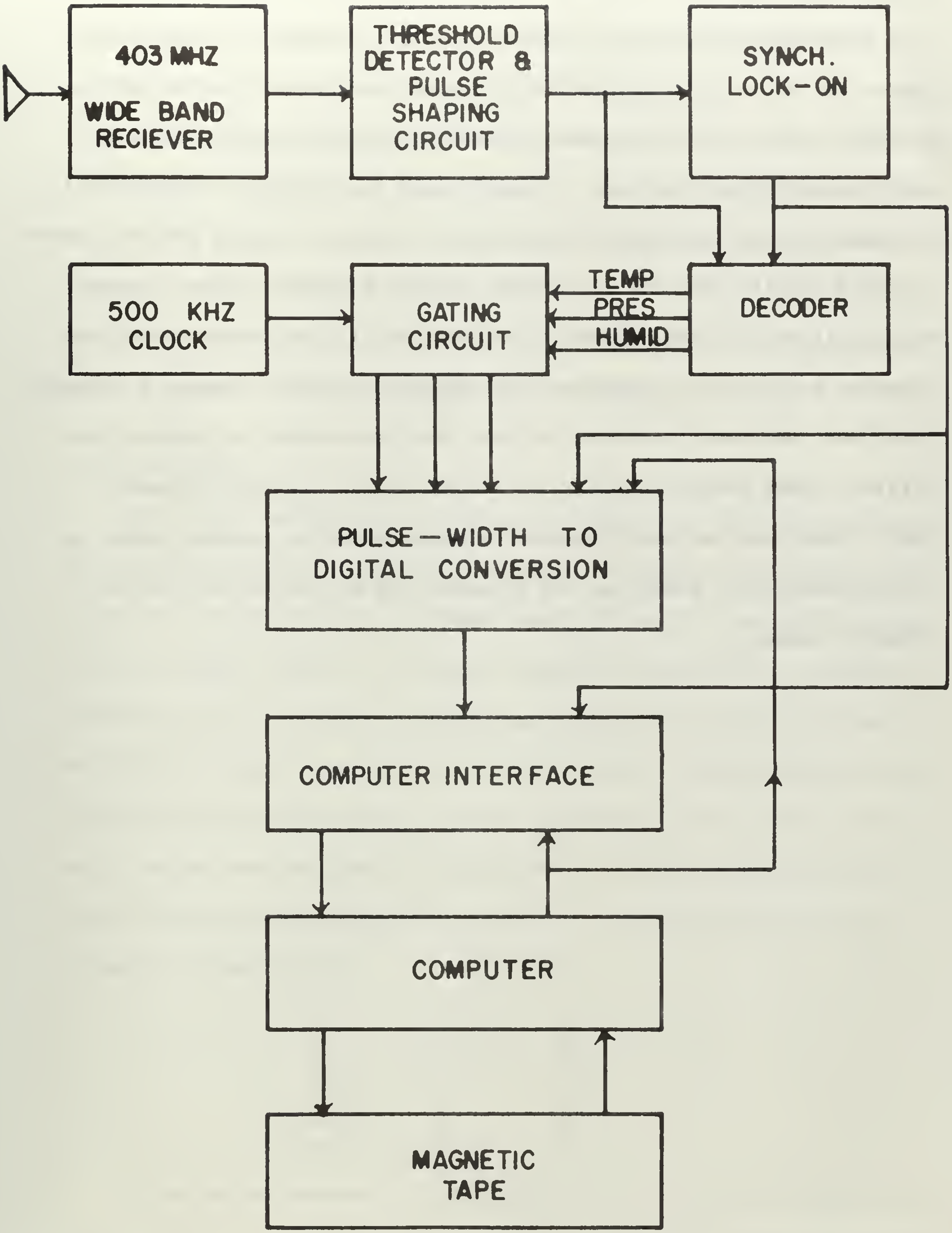

Fig 4 Radiosonde System Ground Station Block Diagram

pressure, and one for humidity, Figs. 3f,3g,3h. The decoded signals are then each gated with a 500 kHz clock.

Pulse width to digital conversion is accomplished by counting the number of cycles of the gated 500 kHz which are present during each respective pulse. In the proposed system, a special purpose computer would control this function. It would also store the raw data directly on magnetic tape for later transmission. However, since a CDC-160 computer and a CDC-163 tape transport were locally available, these systems were utilized. In this manner, construction of a prototype system was somewhat simplified. Therefore, the CDC-160 computer, through a suitable interface, was used to select an input for pulse width to digital conversion, store data in memory, and output blocks of data to magnetic tape. When data has been recorded in this manner on magnetic tape, detailed processing, analysis, and printout may be carried out on any computer system.

4. Circuit Design.

Fairchild Semiconductor devices were used, utilizing integrated micro-circuits whenever possible. The possibility of manufacturing the entire modulator, with the exception of several capacitors, on a single chip exists and a design was produced with that end result in mind. As most of the circuitry was digital, no precise mathematical design was performed. All circuits were laid out in rough form, assembled on vector boards, tested, and corrected as necessary. When the exact configuration and values were determined the various circuits were constructed on printed circuit boards for later interconnection.

4.1 Radiosonde.

The first requirement of the radiosonde was a clock for timing in the modulator. This circuit was designed to produce a 2 ms pulse followed by a 10 ms off time. A quad-inverter (uL-927) was used to form this wave shape, Fig. 5a. A ramp voltage was generated by charging a capacitor with a constant current source during the clock off time and shorting the capacitor during the clock on time. The constant current source improves the linearity of the ramp waveform, Fig. 5b. A suitable counter was designed by using three flip-flops (DTuL-945) and a dual three input gate (DTuL-930), Fig. 5c. The logic table for the counter is shown below:

A	C	D	E
n	0	0	0
n+1	1	0	0
n+2	0	1	0
n+3	0	0	1
n n+4	0	0	0

Switching of sensors is accomplished by connecting a constant current source to all sensors and alternately grounding individual sensors by saturation of a semiconductor, Fig. 6a. Using the values shown, each

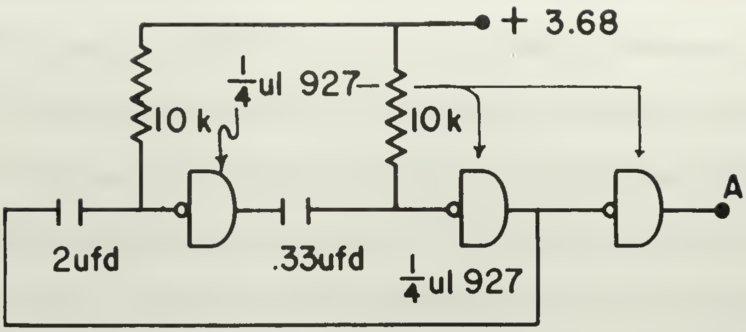

Fig 5a Radiosonde Clock Circuit

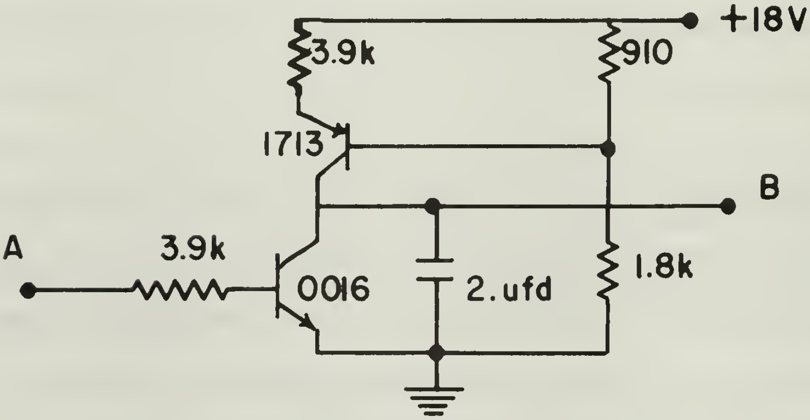

Fig. 5b Radiosonde Ramp Generator

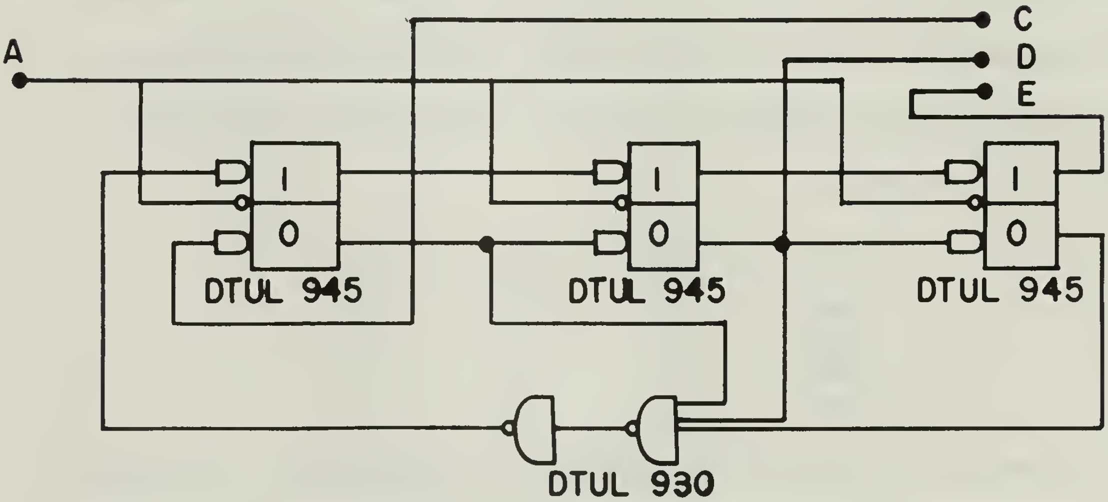

Fig 5c Radiosonde Counter Circuit

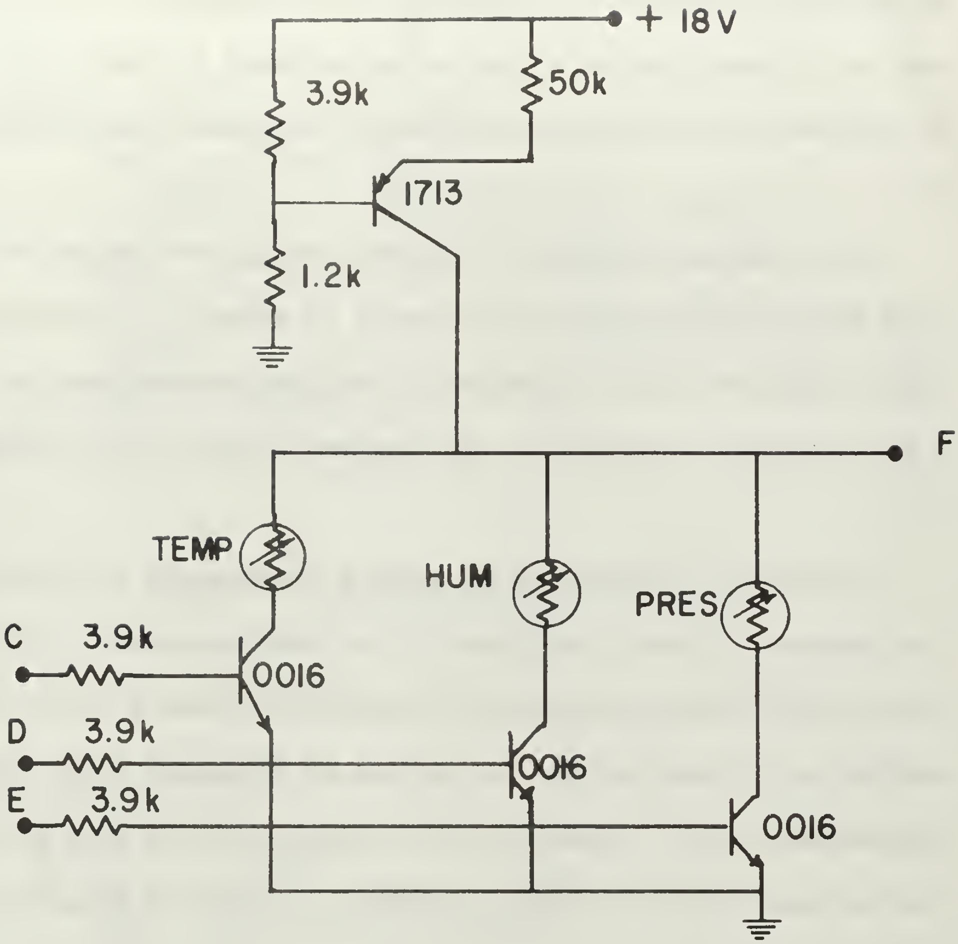

Fig. 6a Radiosonde Transducer Switching Circuit

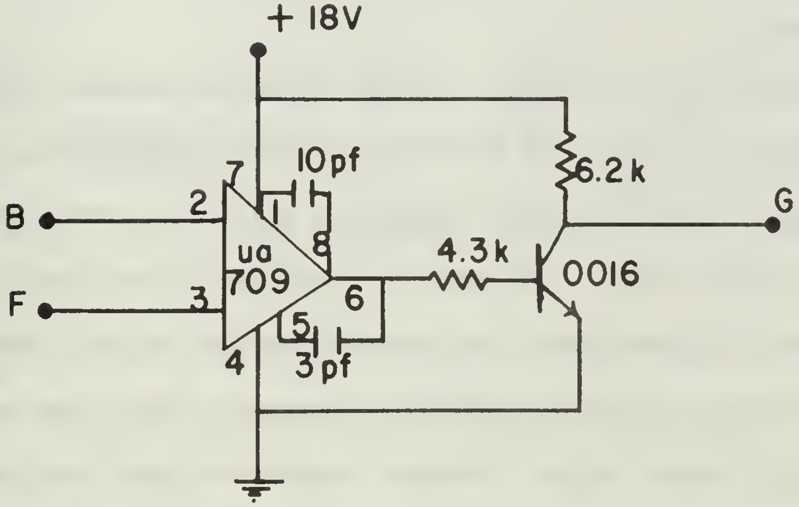

Fig 6b Radiosonde Comparator-Amplifier

sensor may vary from 2000 ohms to 22,000 ohms without producing noticeable heating effects or eliminating the data pulse. A uA 709 operational amplifier was used as a comparator and amplifier. This is possible due to an inverting and a non-inverting input to the uA-709. An inverter follows the comparator and directly modulates the transmitter, Fig. 6b.

As a UHF, solid state transmitter design was beyond the scope of this work, the transmitter section of an AN/AMT-11 radiosonde was modified to operate with this system. This was accomplished by inserting a high voltage transistor in the cathode circuit of the 6026 tube, Fig. 7a.

In order to operate at an ambient temperature as low as -90°C, the modulator circuit was placed in an oven regulated to 70°C. The heating and voltage regulation circuits are shown in Fig. 7b. Voltage regulation is required due to the use of batteries which will deteriorate during flight. Since the pulse widths are set with a voltage level, the voltage level must remain constant in order to obtain meaningful data.

4.2 Ground Equipment.

A standard receiver was utilized. The IF strip was stagger tuned to provide a bandwidth of 2 MHz. A threshold detector and squaring amplifier was designed around a uA-702 amplifier and two sections of a quad-two input gate (DTuL-946). The reference voltage is set with poteniometer P1 to a level slightly above the ambient receiver noise. When the video output voltage is greater than this reference level the uA-702 saturates producing a square pulse. By-pass capacitors shunt the input and output of the amplifier to prevent any feed through of the 30 MHz

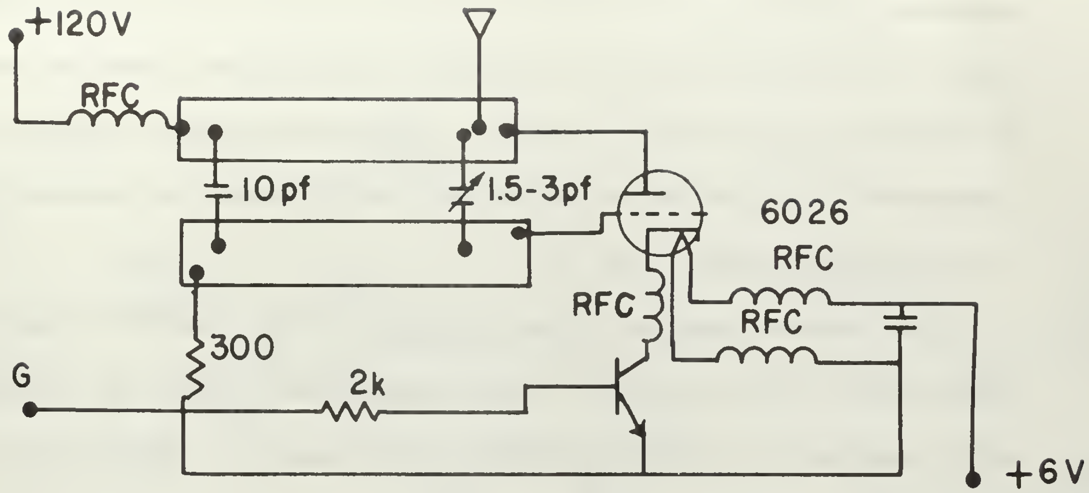

Fig. 7a   Radiosonde Transmitter Circuit

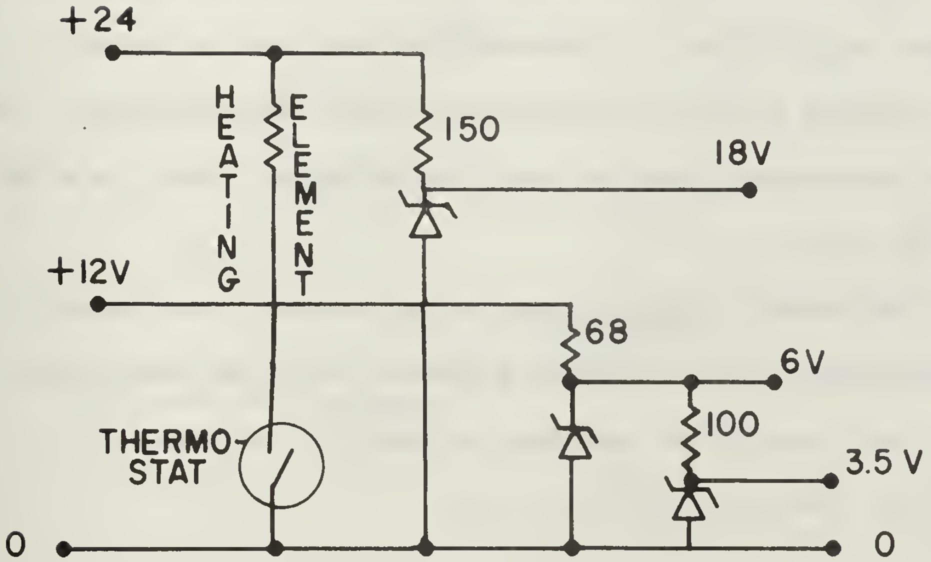

Fig. 7b   Temperature and Voltage Regulation Circuit

IF frequency. This circuit is shown in Fig. 8a.

Synchronization is achieved by charging a capacitor with a variable constant current source during the periods when no pulse is present. An output is produced when the capacitor voltage rises above the switching threshold of the output transistor. The pulse is then shortened by a "one-shot" in order to insure enough time to reset the decoder prior to the next pulse train, Fig. 8b.

The decoder uses two flip-flops (DTuL-945), two three input gates (DTuL-930), and one two input gate (¼DTuL-946). These are interconnected to provide the output described in Section 3.2. The circuit diagram is shown in Fig. 9a.

A 1 MHz crystal oscillator was used to produce a stable reference frequency. The crystal was placed in an oven to improve stability, Fig. 9b. A high gain amplifier (uA-702) was used to buffer the oscillator and to provide amplification. A DTuL-946 gate was used to insure a square wave form and a DTuL-945 flip-flop to count down to 500 kHz. The output taken from another DTuL-946 gate, for increased drive, is a 500 kHz square wave, Fig. 9c.

Each of the decoder outputs (temperature, pressure, and humidity) were gated with the 500 kHz reference frequency using two input gates (DTuL-946). Additional gates were used as inverters to return the waveforms to the proper polarity, Fig. 10a.

4.3 Computer Interface.

In order to use the CDC-160 computer, the negative logic levels (0 and -16 volts) at the input and output cables of the computer were shifted to the positive logic levels (0 and +5 volts) of the microciruits. These circuits were designed and are depicted in Figs. 10b and 10c. Sixteen units of each circuit were required. Since the computer was used as

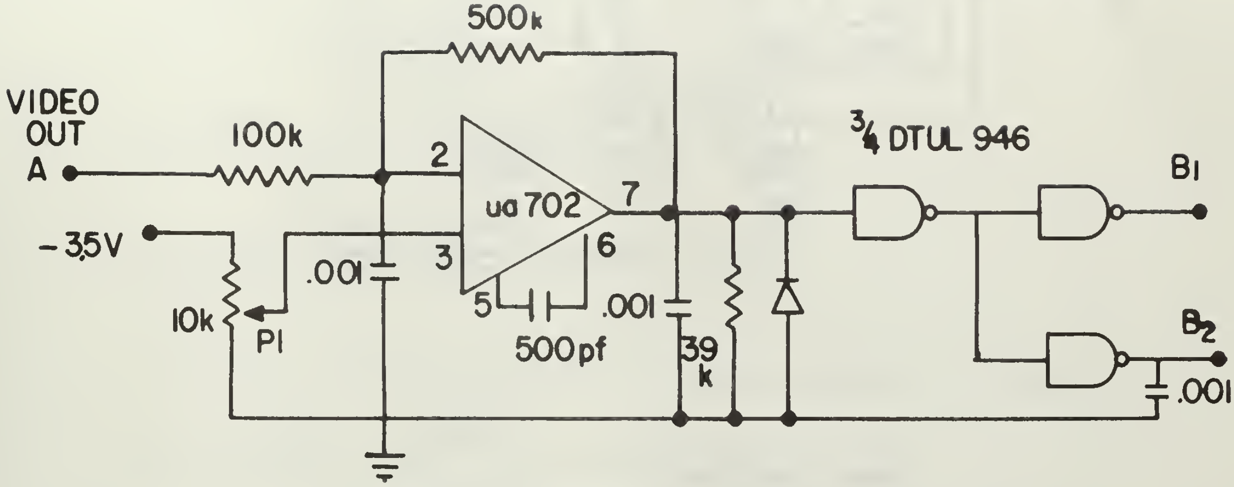

Fig. 8a Receiver Threshold Detector and Squaring Amplifier

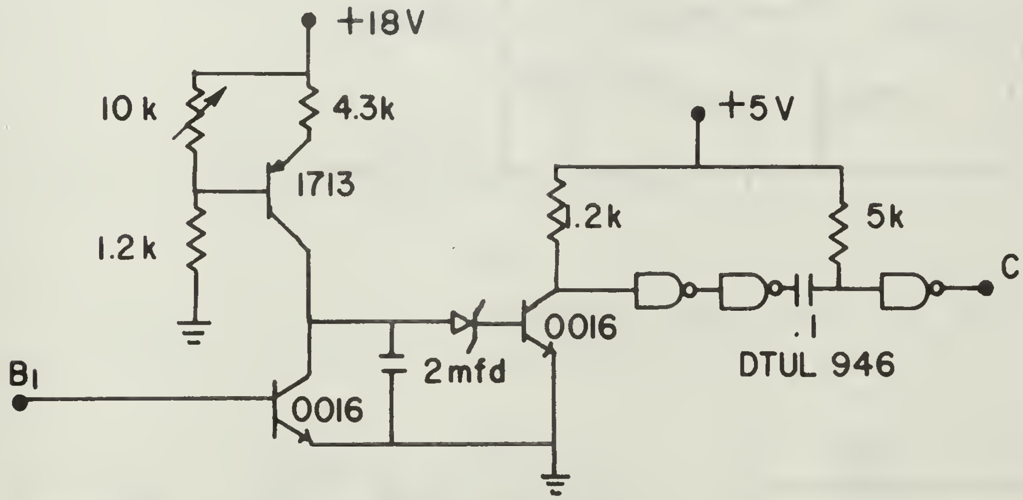

Fig 8b Receiver Synchronization Circuit

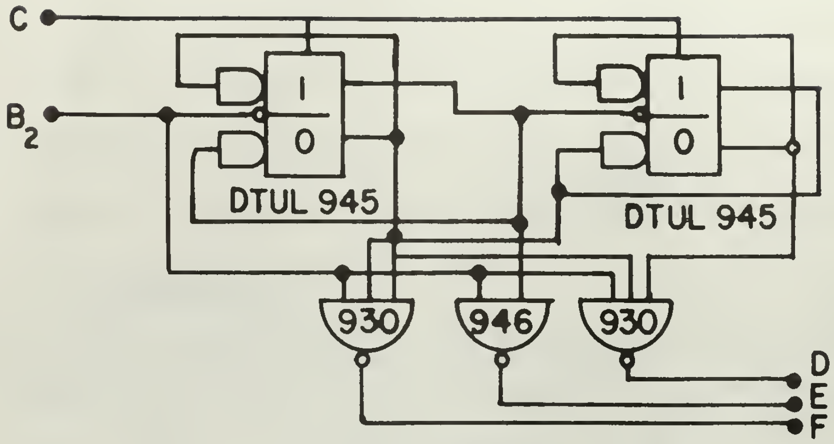

Fig. 9a Decoder Circuit

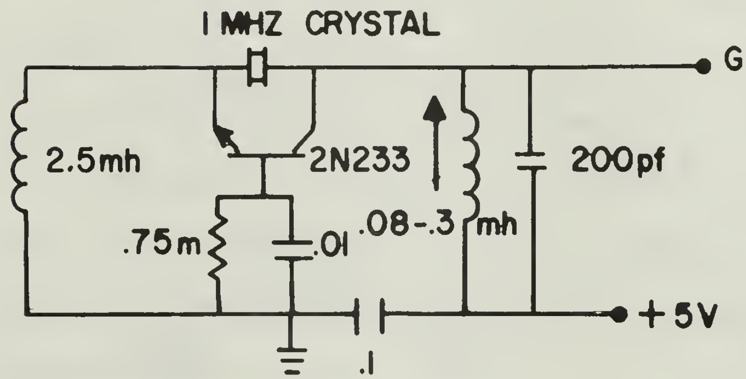

Fig 9b 1 MHz Crystal Oscillator

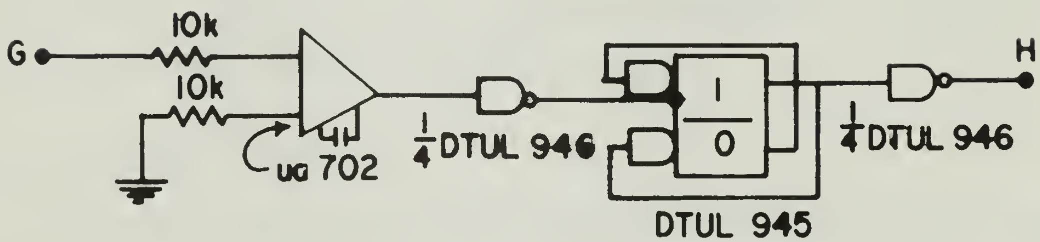

Fig. 9c Buffer Amplifier and Dividing Circuit

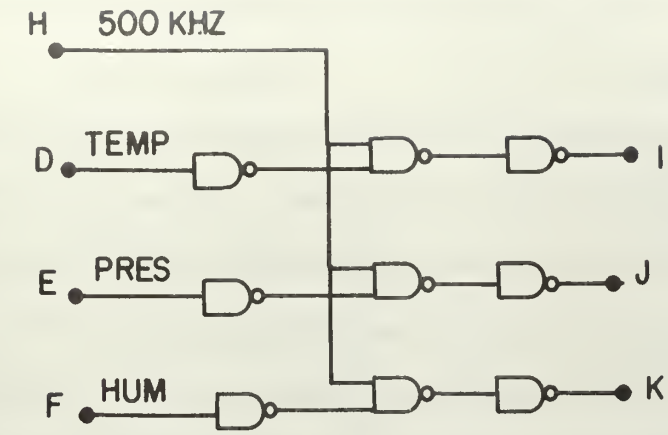

Fig. 10a 500 kHz Gating Circuit

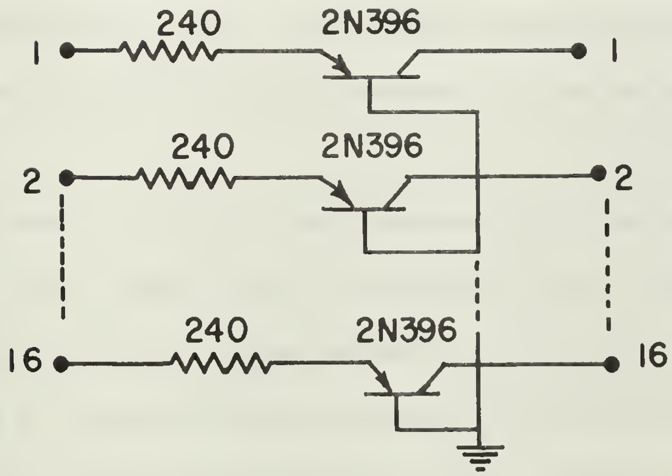

Fig. 10b CDC-160 Input Level Shift Circuit

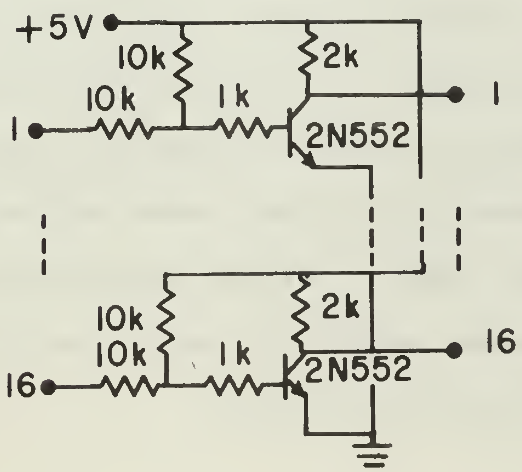

Fig. 10c CDC-160 Output Level Shift Circuit

the control element for pulse width to digital conversion and data input, the interface must be able to recognize output commands from the computer. The octal outputs for the various commands were chosen and are listed in Table II.

The interface was designed to operate as follows. When the computer activates the "function select" line (7500), followed by an output of 0101, an RS flip-flop is set, which activates the temperature channel. When this flip-flop is properly set, the "output resume" line is activated by the interface, thus informing the computer that the function has been properly selected. Upon receipt of "output resume" the computer drops the "function select" and the output lines, which in turn causes the interface to drop the "output resume" line. Thus, the temperature channel has been selected and the computer is free to move to the next program instruction.

In order to input data, the computer must execute an input instruction, for example 7600, which activates the input request line. The interface senses this line and the synchronization input from the decoder. On the first sync pulse, the temperature input channel is gated into the twelve binary counters. Prior to the next sync pulse the temperature pulse, modulated by the 500 kHz reference oscillator, enters the counter which counts in binary the number of cycles of the 500 kHz which are present during the interval of the pulse. On the second sync pulse, the interface activates the information ready line, thus informing the computer that the counters hold a binary number proportional to the temperature pulse width. When the CDC-160 receives the "information ready" signal, the computer samples the counters and stores the information according to the program instruction.

TABLE II

CDC-160 Control Function Codes

CDC-160 OUTPUT		MEANING
Function select	7500 0101	Select the temperature channel
Function select	7500 0102	Select the pressure channel
Function select	7500 0104	Select the humidity channel
Normal output	7410	Clear all channels and counters
Input request	7600	1) On the next sync pulse gate the channel previously selected to the counters 2) On the following sync pulse input the binary number held by the counters.

Upon receipt of the input information the computer drops the input request line, which in turn causes the interface to drop the information ready line. The computer is then free to proceed to the next instruction.

In order to clear the interface, the computer executes an output 0010. The interface senses this output and resets all flip-flops and counters. The interface may also be cleared by depressing the master clear level on the CDC-160 console. Any channel may be selected, sampled, and cleared in the same manner; the only difference being the function select code used. The circuit diagrams used to implement the interface functions are shown in Figs. 11 and 12.

4.4 Assembly.

All of the circuits described were constructed on printed circuit boards using standard techniques. The interface, with the exception of level shifting circuits, was assembled by inter wiring plug-in boards which had been previously prepared. The level shifting circuits were constructed on plug-in boards to facilitate assembly.

Noise and power fluctuations presented a major problem in the decoding circuitry. The high speed and low logic levels of the micrologic elements, coupled with the fact that the flip-flop elements shift on a transient, make them extremely susceptible to noise. Noise is carried through the power lines, and picked up by radiation from the 30MHz IF strip, the 1 MHz clock, and transients caused by the oven thermostat. This problem was solved by using shielded cables for all power and signal lines, placing large capacitors at the power input to circuit boards, and placing shunt capacitors at the input to some flip-flops.

A minor problem was encountered in establishing proper drive levels

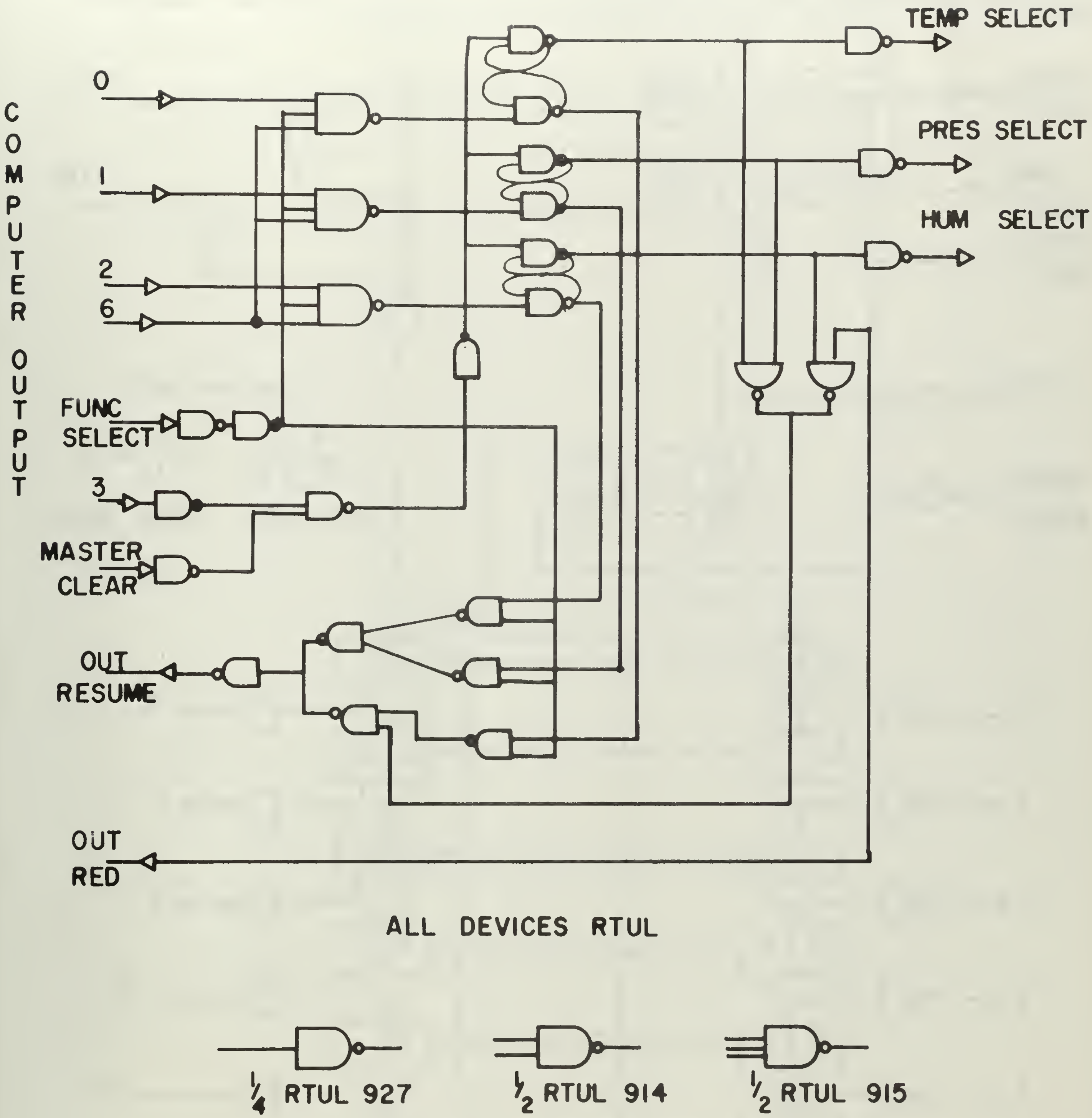

Fig. 11 Interface Select Circuit

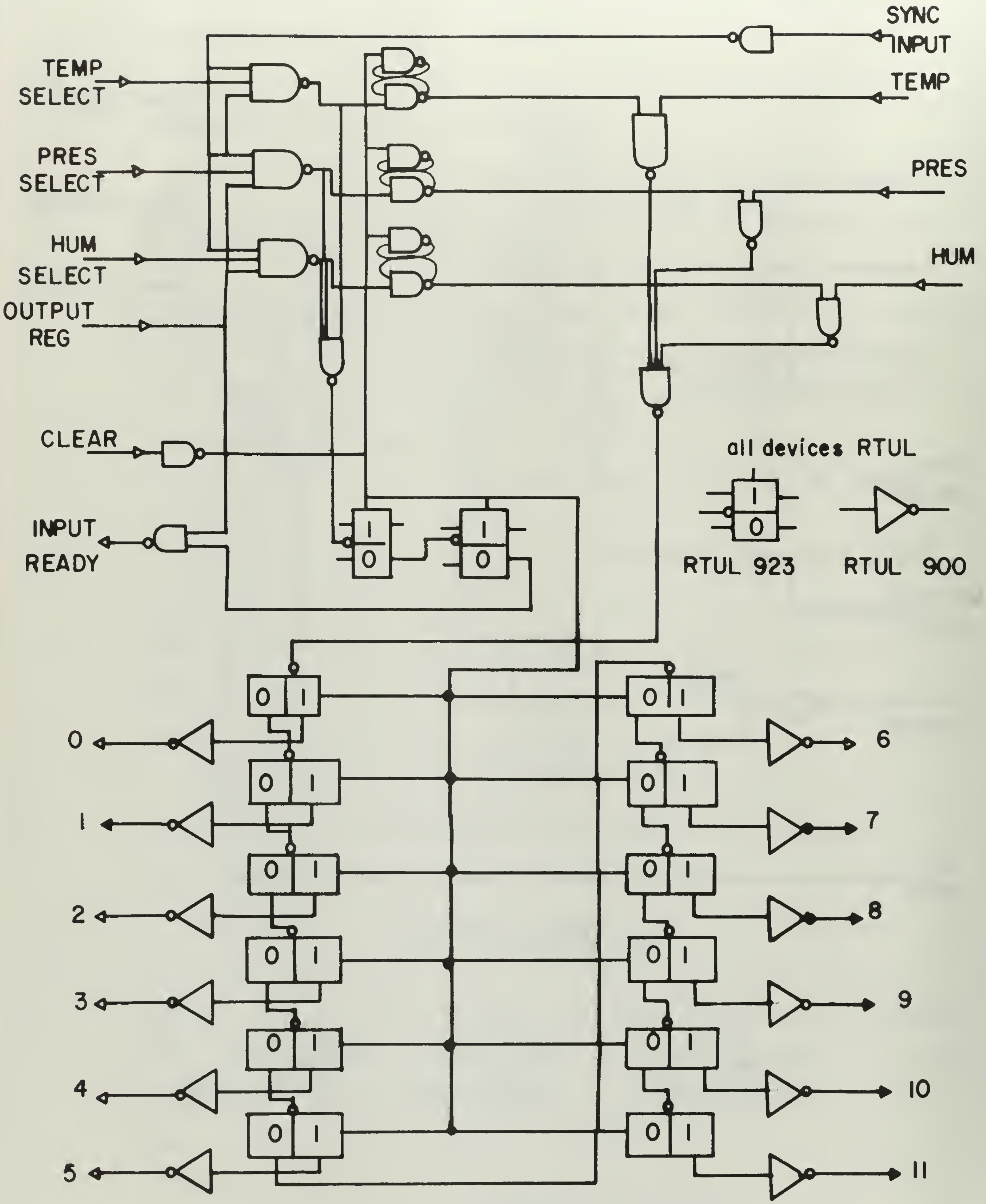

Fig. 12 Pulse Width to Digital Conversion Circuit

between different types of micrologic elements (DTuL and RTuL) and the computer. This problem was solved by using extra drivers where necessary, for example, between the RTuL binary counters and the level shifting circuits.

After a reasonable amount of trouble-shooting, the entire system satisfied the design parameters, and testing of an operational type was commenced.

5. Operational Tests.

In order to determine the radiosonde performance, independent of the receiver and decoder, data was taken using a frequency counter in the interval timing mode to obtain a plot of pulse width versus transducer resistance. The plot of this data, Fig. 13, was relatively linear over the normal transducer range.

Upon completion of the entire system data was taken in order to plot transducer resistance versus computer readout. To obtain this data the computer was programed to select the channel, read data, place data in the "A" register, clear, and return. This program was manually stepped and the output was recorded from the "A" register. The data was obtained in octal form, translated to decimal, and plotted. This plot, Fig. 14, is as expected identical in shape to the plot obtained directly from the radiosonde. Therefore, little or no information was lost in transmission, decoding, and digital conversion. The slight nonlinearity is of no concern because the transducers, in general, are highly non-linear.

The average slope of the curve is .182 per ohm of transducer resistance. The worst case value for transducer resistance versus temperature would be on the order of 100 ohms per degree centigrade (the transducer in use is about 1000 ohms per degree centigrade). Therefore the output sensitivity would be about 18.2 per degree centigrade or 0.05°C.

The next test should consist of placing the radiosonde package in an environmental chamber in which temperature, pressure, and humidity can be independently and collectively controlled. The three parameters of the environmental must be accurately displayed so that data for curves of temperature, pressure, and humidity versus computer output may be obtained. While anyone parameter is varied, the others should be held

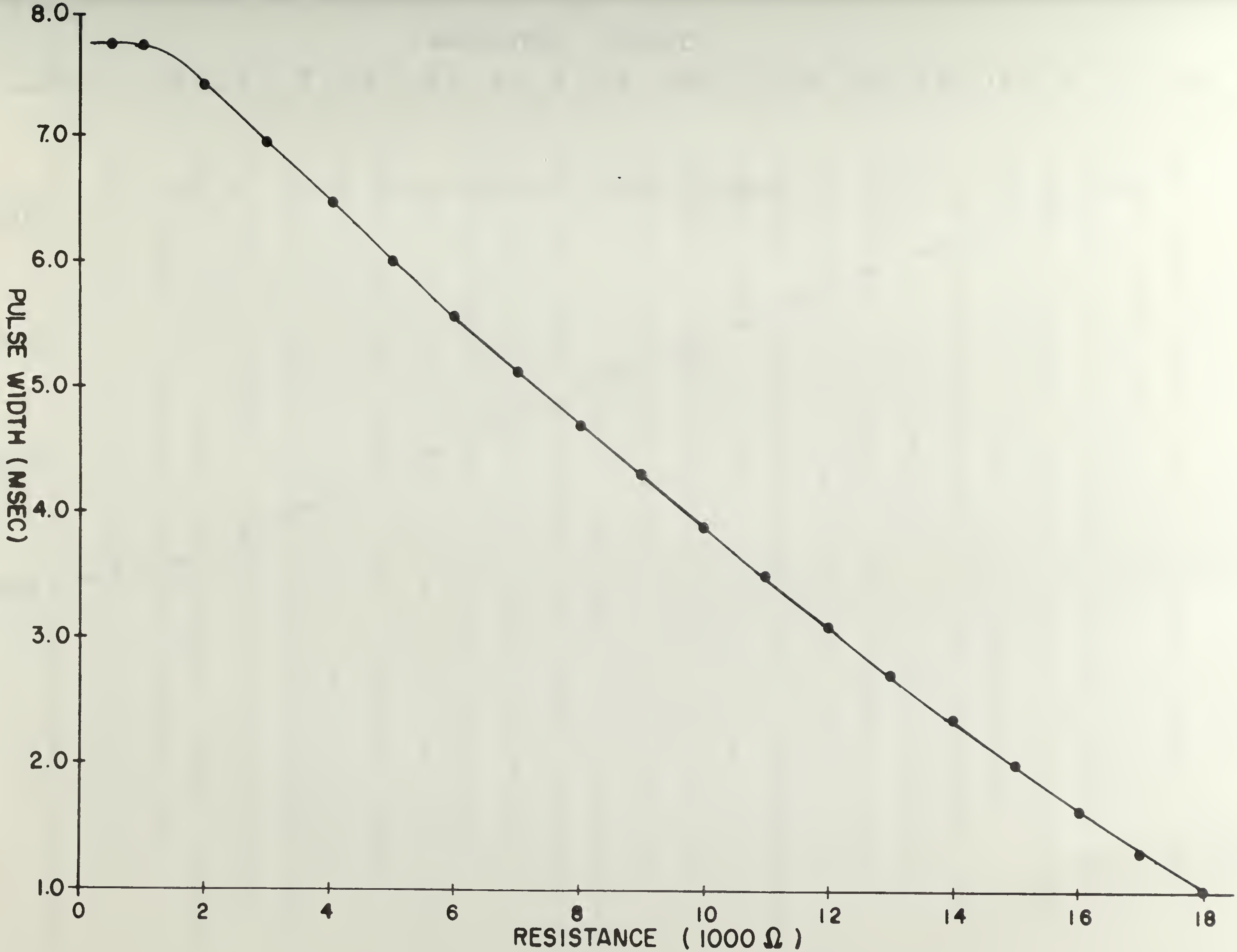

Fig. 13 Plot of Pulse Width vs. Transducer Resistance

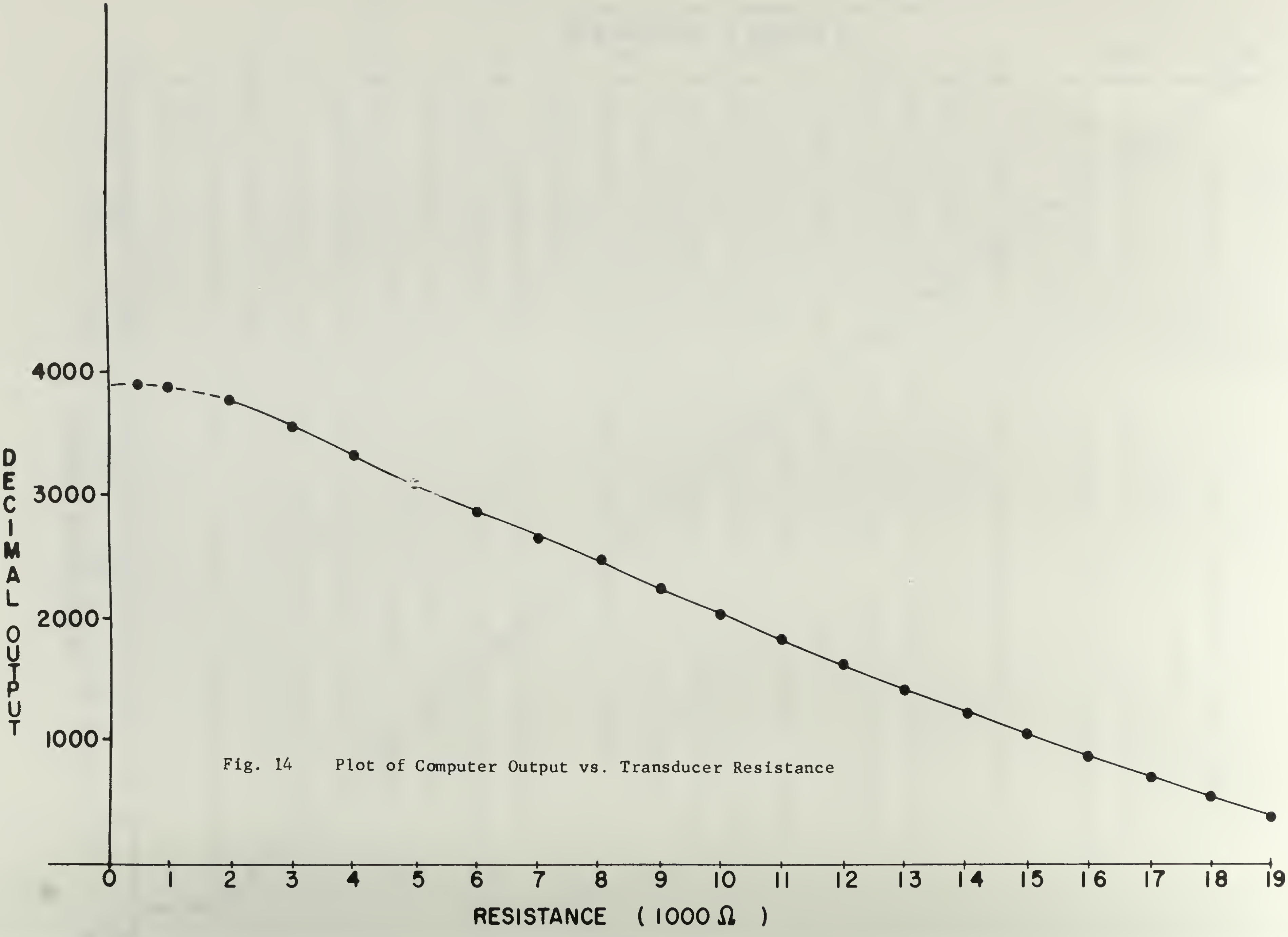

Fig. 14 Plot of Computer Output vs. Transducer Resistance

constant, and the computer readout for all three parameters recorded. In this manner calibration curves may be produced, as well as, curves to correct pressure and humidity for variation due to temperature. This is necessary since all present pressure and humidity transducers vary as a function of temperature. These tests were not made due to the inavailability of a pressure transducer and an environmental chamber.

At this point all data required for computer programming would be available. The first program required is the control program for the CDC-160 computer. The program must cause the computer to read data to a block of memory, output to tape when the block is full,and return. A flow graph of a proposed program is shown in Fig. 15. This program will cause the computer to place the raw data on magnetic tape in files of 3000 words. The computer will run in continuous loops until the data transmission ceases or fades, at which time it will halt with a read instruction in the "z" register. The computer will stop due to the operation of the interface. This stoppage is only apparent to the operator when the status light remains on "IN" continuously, and the tape unit fails to step (normally the tape unit steps about once each minute).

The program for data interpolation on a larger computer will not be covered in this paper. However, it should be apparent that with the aid of the calibration curves discussed previously numerous programming techniques are available to translate the raw data to an accurate temperature, pressure, and humidity. It is worthy of note that meteorologists calculate altitude by an equation using temperature, pressure, and humidity as unknowns. By using this equation in the computer program all parameters could be printed out or graphed as a function of altitude.

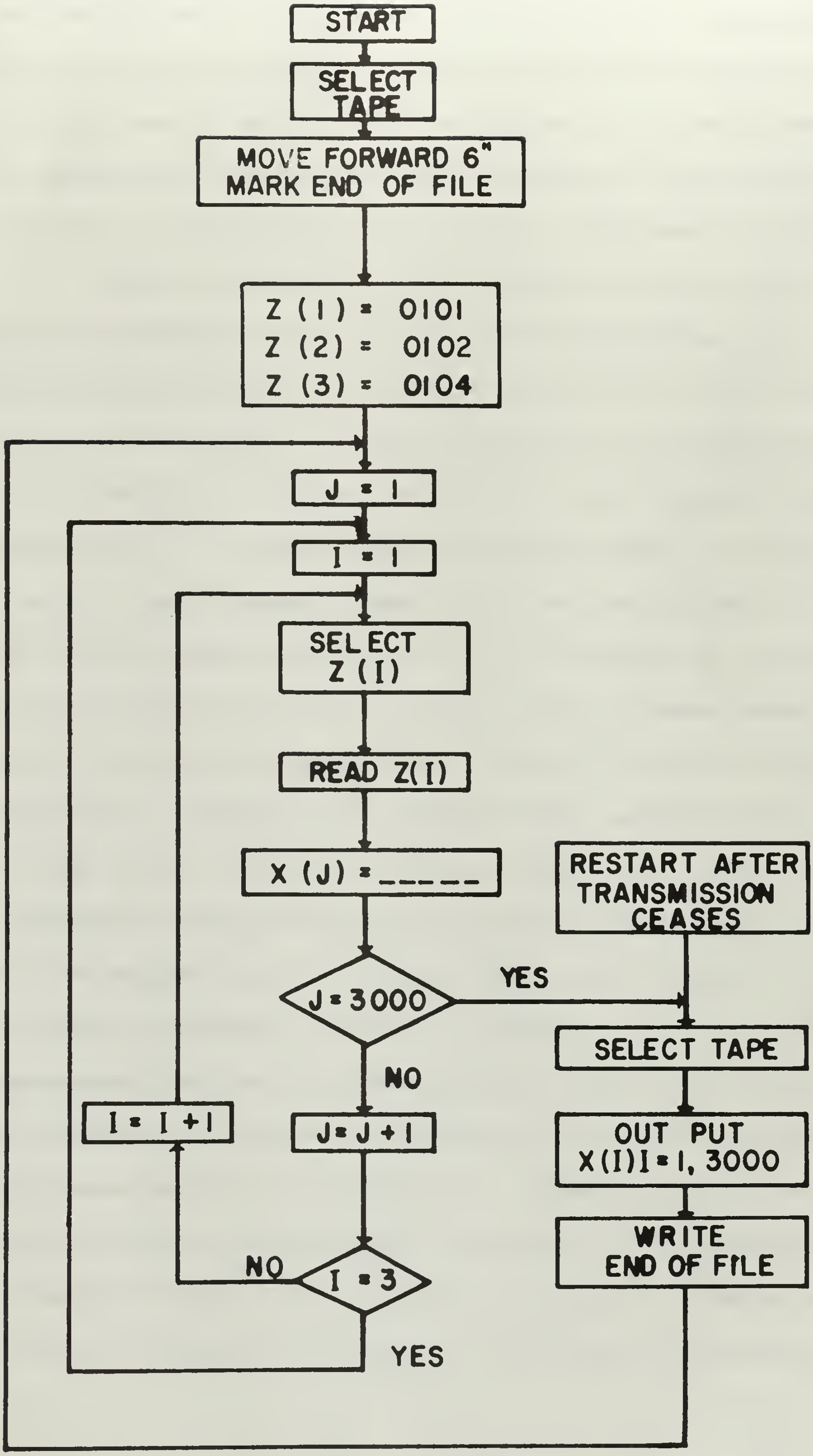

Fig. 15 CDC-160 Control Program Flow Chart

6. Summary.

The proposed system as tested indicated many improvements over the existing system. The digital radiosonde meets or exceeds all design criteria as previously stated. It inherently has the speed, accuracy, and simplicity required to further the meteorological study of the upper air, and to enhance the feasibility of real time weather forecasting. Channel capacity is virtually unlimited as long as slowly varying functions are sampled. Accuracy is limited only by the transducers which are economically available.

This system would also be useful in many other areas such as medical research, where several sources of data are required to be transmitted from a remote location for on line processing.

The author highly recommends further development of this system, especially in the areas of pressure and humidity transducer design and solid state UHF transmitter design.

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A study of the present methods and equipments used in obtaining upper air meteorological data indicated a need for a new system capable of interfacing with digital equipment. This work deals with establishing the parameters, methods of implementation, circuit design, construction, and testing of such a system. Sampling, pulse width modulation, time multiplexing, pulse width to digital conversion, and interfacing with the digital computer are discussed. The proposed integrated circuit radiosonde system was constructed and tested with results indicating an improvement over the existing methods.

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